climate change

RESEARCH INFORMATION NOTE

Note Number 6 2007

Carbon Storage in Ontario's Forests, 2000-2100

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Introduction

One of the greatest challenges society is facing is rapid climate change resulting from the addition of greenhouse gases to the atmosphere, mostly in the form of carbon dioxide (CO_2) from the burning of fossil fuels. If left unchecked, the effects of climate change on natural environments will inevitably affect people as well (IPCC 2001). In addition to many other societal benefits, forests store large amounts of carbon (C). As a result, it is important to understand how forest management and natural processes affect forest C storage. Such knowledge can be used to manage forests so that they function as carbon sinks and help reduce greenhouse gas concentrations in the atmosphere.

Trees remove CO_2 from the atmosphere and convert it into organic compounds, the most plentiful of which are cellulose and lignin—the main components of wood. About half of every kilogram of wood is C and every kilogram of C that is in a tree represents about 3.7 kilograms of CO_2 removed from the atmosphere. For this reason, forests have the ability to reduce the build up of atmospheric greenhouse gases and contribute to efforts to reduce global climate change.

Ontario's forests are important to the global C cycle due to their vast extent: the province's forests cover an area of 712,200 square kilometres and represent 2% of the world's forests (OMNR 2002). Ontario's managed forests also help reduce greenhouse gases in the atmosphere by C storage in wood products. In forests, most of the C is stored in two pools: the soil and standing live trees. Carbon is also stored in standing dead trees, understory vegetation, woody debris, and in the forest floor, but the amount of carbon in these pools is small compared to that in soil and live trees. While forest soil usually contains the most C, it is also the most stable. In comparison, C stored in living trees is variable as forests go through cycles of stand regeneration, rapid growth, maturity, and disturbance.

Most of the forests in Ontario are publicly owned and are to be managed for the public good. Most forestry practiced in Ontario occurs in 47 forest management units (Figure 1). These forest management units overlay a province-wide band of forest with northern and southern limits of approximately 51° and 45° N, respectively. Forest management units range from about 130,000 to 1,600,000 hectares (ha) and from hardwood-dominated stands in the more southerly Great Lakes–St. Lawrence forest region to northern conifer-dominated boreal forests, which are subject to stand-replacing fires. Each forest management unit is managed according to a forest management plan, which includes a projection of future stand composition, modelled using a timber supply model.

The most commonly used timber supply model in Ontario is the Strategic Forest Management Model (SFMM) (Kloss 2002). Using SFMM, the age class and species composition of the forest is described at the start of the simulation period, and the future age class and species composition of the forest is modelled as stands grow, are harvested, affected by natural disturbance, and undergo natural succession or receive silvicultural treatment.

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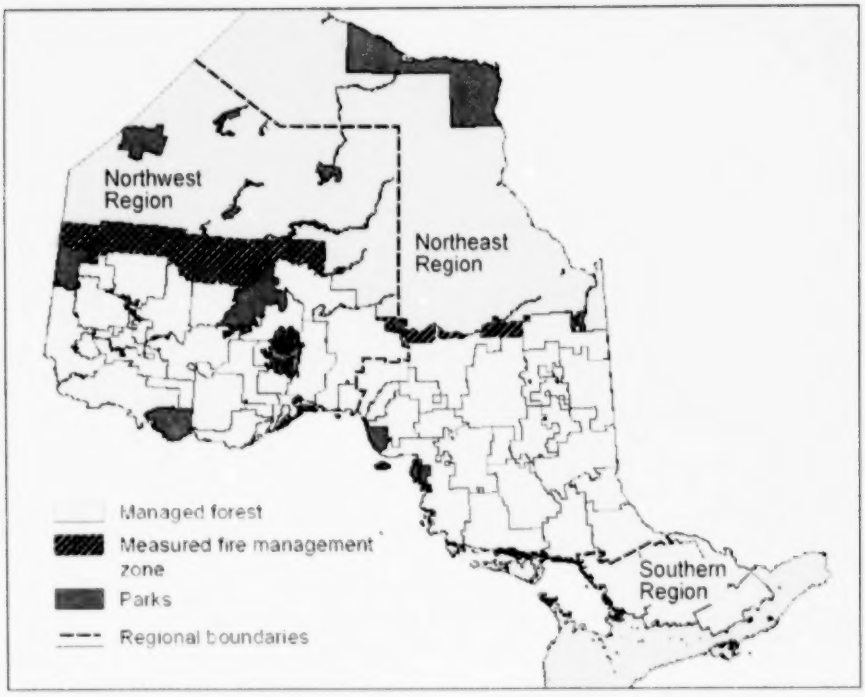

Figure 1. Administrative boundaries of Ontario's 47 forest management units, the measured fire management zone, and major parks.

The amounts of C stored in Ontario's forests and wood products, the duration of storage, and the potential for increased storage through silviculture is important to the global C cycle. These can be predicted using computer models that convert information on the state of the forest (its age and species composition) into values of C in all the live and dead organic matter pools in which it occurs. This report uses data about Ontario's forest structure and information from the forest management planning process and past harvests to describe C in forests and wood products today and through to the end of this century.

Methods

In order to make C projections congruent with forest management plans, we modified the U.S. national forest C model, FORCARB2, to predict Ontario's forest C budgets using SFMM model outputs (Boivin et al. 2005). The modified forest C model, which we call FORCARB-ON, predicts C in live trees, understory vegetation, forest floor, standing and down dead wood, and soil. FORCARB-ON makes most of its predictions based on parameters describing the relationship of merchantable timber volume to the size of each C pool. Although FORCARB2 was parameterized for Great Lakes State forests that border much of Ontario, we parameterized many of the C pools in FORCARB-ON using Ontario, Manitoba, and Quebec data, as appropriate (Chen et al., in review).

Another significant change made to develop FORCARB-ON was the addition of a module to simulate the effect of wildfire on forest C. In SFMM, each forest management unit has an assigned fire interval (e.g., a management unit with a fire return interval of 250 years means that 0.4% of the area in the forest management unit burns annually). Based on the fire return interval, in each year of the simulation fire disturbs the same fraction of forest of all age classes and species types. The area of each forest type and age class that is projected to burn is extracted from SFMM, and C fluxes among pools in these areas are estimated in FORCARB-ON based on empirical knowledge of post-fire forest C dynamics (Chen et al., in review).

Predictions of forest C in Ontario's provincial forest management units used SFMM simulations based on selected management alternatives from the management plans. We also accounted for C in areas of managed forest outside of the forest management units (Figure 1), including forested provincial and national parks, private land, and the measured fire management zone[1] where fires are suppressed once detected, however, if initial suppression efforts fail, an assessment is made to determine if the benefits of continued suppression exceed the costs (OMNR 1997). Forest C estimates for those areas were produced using C values for similar forests in adjacent forest management units, using carbon densities in forest management units as multipliers. Unmanaged forest north of about 51°N latitude and small areas of privately owned forest outside of forest management units in southern Ontario and Manitoulin Island are not covered in these estimates of the forest C stocks.

Wood products are an integral part of Ontario's forest C cycle. In addition to being an important C sink, they contribute to greenhouse gas reduction by replacing more energy-intensive materials (such as steel and aluminum) as well as being a renewable energy source (IPCC 2001). Thus, a complete picture of the forest C budget must include wood products (Kurz et al. 1992, Marland and Schlamadinger 1997). The size of Ontario's present wood products C pool was estimated based on harvest between 1951 and 2000 and C retention and redistribution curves for wood products (Chen et al., in preparation). Estimates of the size of Ontario's wood products C pool from 2000 to 2100 are projected using harvest rates described in forest management plans.

Results

Our estimates show that Ontario's managed forests stored 6,320.3 million tonnes of C in 2000 (Table 1). This is the equivalent of 23,176.5 million tonnes of CO_2. The largest portion of this is C stored in provincially owned managed forests, in which about 5,400 million tonnes C were present in 2000. This was split among C in forest management units (4,278.0 million tonnes), forested parks (579.2 million tonnes), and forests that are protected from fire but where otherwise little management occurs (541.5 million tonnes). The forest C sink we report accounts for C stored in forests as well as C stored in wood products. For Ontario forests harvested between 1951 and 2000, wood products still in use or in landfills were a C stock of 125.8 million tonnes in 2000.

The total carbon stock in OMNR's three administrative regions (Figure 1) is largest in the Northwest at almost 3,000 million tonnes and least in the Southern Region at just under 700 million tonnes (Table 1). Differences in size of carbon stocks by region are attributable to the comparatively small size of the Southern Region, which totals about 1.8 million ha of forest compared to about 12.6 million ha for the Northwest and 14.1 million ha for the Northeast regions. On a per hectare basis, forests in the Southern Region contain more carbon, averaging almost 200 tonnes C per ha compared to slightly less than 150 tonnes per ha in the northern regions.

Projected changes in C stored in Ontario forests from 2000 to 2100 are presented in Figure 2; the changes are presented by administrative region relative to C stock levels in 2000. These changes do not include C stored in wood products. The total C pool of managed forests (including wood products) is projected to increase by almost 7% (433.8 million tonnes) by 2100 (Figure 3). While C stocks in all of the types of managed forest are projected to increase between 2000 and 2100, their combined growth is projected to be 69.4 million tonnes, compared to an increase in the wood products pool of about five times the amount in forests.

Discussion

For any forested area, C stocks fluctuate over time. As seen in Figure 2, total forest C stocks in the Northwest and Southern regions are projected to have a positive balance relative to their level at 2000 throughout the entire projection period (2000-2100). Forest C stocks in the Northeast Region, however, are

[1]The measured fire management zone was revised in 2004 and renamed the Northern Boreal Zone (OMNR 2004). For this report we define the measured fire management zone according to the approach used earlier by the Aviation and Forest Fire Management Branch (OMNR 1997) encompassing the areas shown in Figure 1 of the present report. This somewhat underestimates the area now receiving measured fire protection.

Table 1. Projected carbon stocks (millions of tonnes) in Ontario's forests and wood products from 2000 to 2100, estimated using FORCARB-ON based on approved forest management plans.

Region	Year	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Northwest Region	Forest management units	1890.2	1882.5	1880.0	1884.7	1891.6	1896.5	1901.4	1905.7	1910.0	1911.8	1908.8
	Private forest land	143.9	144.9	145.4	145.5	144.8	143.4	142.0	141.5	142.1	143.1	143.7
	Measured fire management zone	444.7	453.0	458.2	460.0	459.6	457.4	455.7	456.4	459.7	462.7	464.2
	Parks[a]	442.3	449.5	453.3	453.8	451.9	447.9	444.3	443.5	446.0	450.1	452.6
	Wood products	0.0	22.6	43.2	61.6	79.0	96.0	113.0	129.7	147.2	164.6	182.2
	Sub-total	2921.2	2952.5	2980.2	3005.6	3026.8	3041.3	3056.5	3076.8	3105.0	3132.2	3151.5
Northeast Region	Forest management units	2040.0	2041.6	2046.6	2047.6	2043.2	2036.5	2028.8	2026.8	2028.9	2032.3	2033.1
	Private forest land	327.3	334.4	339.0	340.2	338.8	335.7	332.0	329.6	329.7	331.5	333.5
	Measured fire management zone	96.8	97.0	96.2	95.1	94.1	94.2	95.0	96.2	97.2	98.1	98.6
	Parks[a]	110.2	113.1	115.2	116.1	115.5	113.6	111.7	110.9	112.0	113.7	115.2
	Wood products	0.0	20.2	38.7	56.0	72.3	87.8	103.2	118.2	133.6	149.6	165.1
	Sub-total	2574.2	2606.3	2635.8	2655.1	2663.9	2667.7	2670.8	2681.7	2701.3	2725.2	2745.6
Southern Region	Forest management units	348.1	351.1	351.7	350.6	348.8	346.4	345.8	346.4	347.6	348.8	349.6
	Private forest land	324.3	334.8	340.8	343.0	339.9	335.4	333.4	333.6	334.7	336.0	336.4
	Parks[a]	14.5	15.1	15.5	15.7	15.4	15.1	15.0	15.1	15.3	15.4	15.5
	Wood products	0.0	4.6	9.0	13.0	17.0	21.1	25.1	29.2	33.3	37.4	41.4
	Sub-total	686.9	705.6	717.1	722.3	721.1	718.1	719.3	724.3	730.8	737.6	742.9
Historical wood products[b]		125.8	122.2	118.5	115.1	112.0	109.4	107.1	105.4	104.0	102.5	101.5
Total wood products (historical plus future)[b]		125.8	169.6	209.4	245.7	280.3	314.3	348.4	382.5	418.1	454.1	490.2
Small parks[b,c]		12.3	12.5	12.6	12.7	12.6	12.5	12.4	12.3	12.4	12.5	12.6
Total Ontario forest and wood products carbon stock		6320.3	6399.0	6464.2	6510.7	6536.5	6548.9	6566.0	6600.6	6653.5	6710.0	6754.1

[a] Parks larger than 1,000 ha. [b] Regional breakdown not available. [c] Parks smaller than 1,000 ha

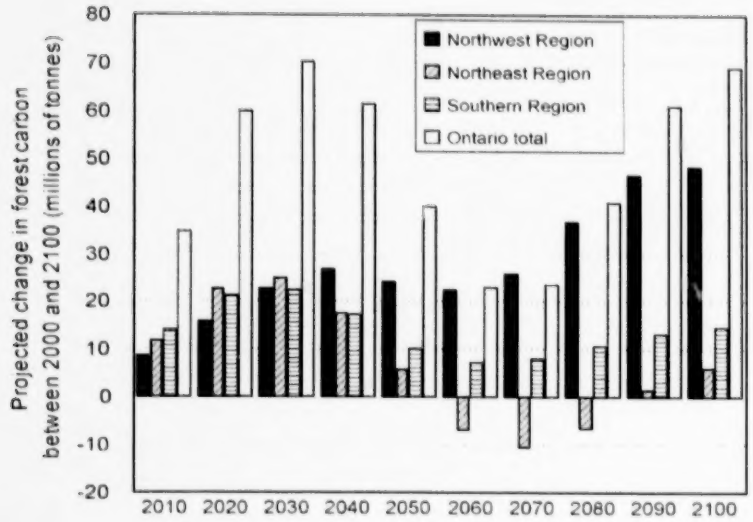

Figure 2. Projected change in carbon stocks in Ontario's forests in MNR administrative regions between 2000 and 2100, estimated using FORCARB-ON based on the approved forest management plans. For each set of bars at decadal intervals, carbon change was estimated as the difference from the stock level in 2000. Carbon stored in wood products is not included.

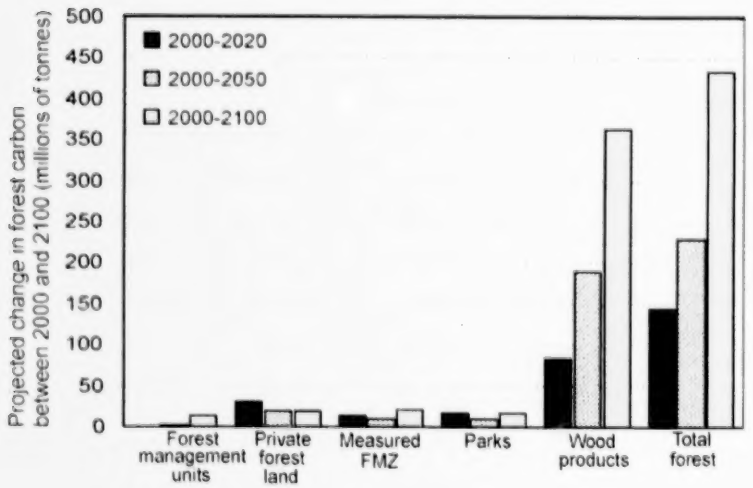

Figure 3. Projected change in carbon in Ontario's forest and wood products carbon stocks from 2000 to 2020, 2000 to 2050, and 2000 to 2100, estimated using FORCARB-ON based on the approved forest management plans. The wood products carbon stock includes harvest from 1951-2020, 1951-2050, or 1951-2100; 1951 was used as a starting year because harvest data for preceding years were unavailable at the time of simulations.

projected to briefly dip below their 2000 level between 2060 and 2080, and then increase above the 2000 level by the end of the century. These C changes largely reflect differences in the forest age structure within the administrative regions. On average, regenerating stands contain relatively less C and their rate of C sequestration is low. As stands reach crown closure their rate of C sequestration increases, as does the C stock they contain. In mature and overmature stands, the amount of C is high but its rate of increase is near zero or may be negative, as older trees die and decay and successional changes occur. In addition to the above growth dynamics, a disturbance (either natural or harvest) at any age causes a significant change in stand C sequestration, bringing it to near zero.

This pattern persists at larger scales. If the area under consideration is dominated by relatively young, fast-growing forests, total C stocks will tend to increase over time, barring a major disturbance. In contrast, if the overall age structure of the area is skewed towards mature forests, the total C stocks will tend to decrease as a result of successional changes and the higher incidence of natural and human-induced disturbance (harvest).

The short-term reduction of forest C stocks projected for the Northeast region from 2060 to 2080 emphasizes the importance of selecting an appropriate time frame when assessing changes in forest C stocks. Despite a 30-year period when the C stocks of the Northeast region declined, the region was a C sink when considered from 2000 to 2100. For any given area, it is possible to select a period when the C stocks are decreasing. Small-scale and short-term variations in C stocks are less important than overall trends in C. While we report decadal changes in C stocks in this report, longer periods are required to properly interpret the effects of forest management on C, with the period being at least the same as the harvest rotation or natural disturbance cycle, and preferably longer.

Between 2000 and 2100, the size of the managed forest sink in Ontario is projected to increase by 69 million tonnes. Over the same time, an additional 364 million tonnes of C will be stored in wood products from Ontario forests. While these are large amounts of stored C, they are small if one extrapolates recent levels of greenhouse gas emissions to the end of the century (Environment Canada 2006).

Burning fossil fuels releases large amounts of CO_2 into the atmosphere. Most scientists have concluded that if the release of CO_2 and other greenhouse gases continues at its present rate, before long it will dramatically change the climate of the planet (IPCC 2001, NAS 2006). According to the Canadian Council of Forest Ministers (2006), increasing forest C could help to mitigate climate change. It can be inferred from this statement that using forest management to increase C storage is desirable, so long as it supports the overarching goals of forest sustainability. The Kyoto Protocol recognizes the importance of forests to the global C budget and promotes C sequestration through afforestation, avoided deforestation, and forest management (IPCC 2000). Opportunities exist to increase Ontario's forest C sinks using management practices to promote rapid regeneration of fully stocked stands (e.g., site preparation, competition control, and planting or seeding) and to increase stand growth (e.g., genetic improvement, fertilization) (Colombo et al. 2005).

While silviculture can increase future C stocks, the most significant factors affecting forest C dynamics are natural and human-induced disturbances, which in Ontario are primarily wildfire and timber harvesting. While not all of the ecological effects of harvesting are the same as those of fire, these two disturbances both affect forest age structure over large areas and tend to create conditions favourable for the regeneration of disturbance-adapted species. To meet the economic needs of society while maintaining the role that wildfire has historically played in shaping Ontario forests, forest management in Ontario aims to control wildfires and replace them with harvest that must, to the greatest extent possible, emulate fire disturbance patterns (and thereby mimic certain ecological processes) (OMNR 2001). The impacts of wildfire and harvest on forest C are also similar in that both remove large quantities of C from the living biomass pool and create conditions for the growth of new forest that will subsequently sequester large amounts of C from the atmosphere. However, this is where the similarity ends. Fires release large amounts of C directly to the atmosphere by combustion and, in decades following the fire, by decomposition of fire-killed trees (Amiro et al. 2002). In comparison, most of the C removed through forest harvest is not released to the atmosphere but is captured and stored in wood products. Our projections show that by the end of the century, almost 500 million tonnes of C will be stored in wood products from Ontario forests. Therefore, we submit that regulated forest harvest in Ontario increases forest C over the long term when both the forest and wood products pools are accounted for.

In Ontario, wood product C is projected to increase more than forest C pools. The wood products pool used to create estimates for this note accounts for wood products that are in use and those that are placed in landfills. It does not, however, account for reductions in greenhouse gas emissions resulting from the replacement of fossil fuels by energy generation from wood, or from the displacement of energy-intensive materials such as steel and other metals or the release of CO_2 from the curing of concrete. Our estimates also do not account for fossil fuel used in harvesting and transporting trees to mills or to manufacture the wood products. Domtar reported average greenhouse gas emissions from the manufacture of paper products as 0.82 tonnes CO_2 equivalent per tonne C in paper and 0.051 tonnes CO_2 equivalent per tonne C in sawn lumber (Domtar 2001). In comparison, Tembec's Spruce Falls, Ontario, paper operation had an efficiency of 0.458 tonnes CO_2 equivalent per tonne C in paper in 2000, but this did not include emissions from purchased electricity (Tembec 2001). Abitibi

Consolidated (2003) estimated that in 2001, their sawmilling operations released 0.051 tonnes CO_2 equivalent per tonne C in sawn lumber and across their 17 pulp and paper mills an average of 0.608 tonnes CO_2 emissions per tonne C of product (Abitibi Consolidated 2003).

Our estimates show that between 2000 and 2100, the amount of carbon stored in wood products will grow by over 360 million tonnes. This will far outweigh the growth of carbon sinks in the forests themselves. While the long life of solid wood products such as furniture and building materials is self-evident, paper and paper products also store carbon for long periods of time, because after a relatively short period of initial use they are either recycled and remain in use or are placed in landfills where they decompose slowly (Micales and Skog 1997, Skog and Nicholson 2000). The rate of decomposition in landfills is so slow that according to Micales and Skog (1997), on average only 26% of C from paper in a landfill is potentially released to the atmosphere as CO_2 and methane. The rest of it turns into a nonreactive solid mass, similiar to humic material, which remains permanently sequestered in the landfill where its contribution to greenhouse gas emissions is negligible (Micales and Skog 1997). It is possible to double methane gas collection from landfills in Canada, which would further improve the emissions balance of wood products (Environment Canada 2002).

Ontario's greenhouse gas emissions increased by 27 million tonnes from 1990 to 2004, an increase of about 15%; growth was due mostly to increased emissions from energy generation and transportation (Environment Canada 2006). Reducing Ontario's 2004 greenhouse gas emissions to 6% below their 1990 level would require a decrease equivalent to 37 million tonnes of CO_2 emissions per year. In contrast, from 2000 to 2100, Ontario forests are projected to sequester on average about 4.3 million tonnes C every year in forests and wood products (equivalent to 15.9 million tonnes of CO_2 per year).

The changes in forest C stocks described here are based on projections generated by the model FORCARB-ON. These projections require large amounts of input data and are affected by assumptions and parameters of the model. The development of FORCARB-ON is an ongoing process; as more data become available, model assumptions and parameters will be re-evaluated and adjusted as needed to reflect the developing state of knowledge of forest C dynamics. While updates in input data and in FORCARB-ON itself may result in some changes in the projected forest C values, we expect the overall C trends to remain about the same as those presented.

Conclusions

Ontario's managed forests are projected to increase C storage by 433 million tonnes from 2000 to 2100. The largest forest sink will be in wood products, accounting for 364 million tonnes of C storage over the century. This equates to an annual rate of C sequestration of 4.3 million tonnes between 2000 and 2100, which is equivalent to 15.9 million tonnes of CO_2. Our projections demonstrate the importance of assessing trends in forest C stocks over longer periods of time to avoid short-term effects of changes in forest structure. We also conclude that when wood products and forests are both accounted for that sustainable forest management increases the total C stock over the long term.

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Stockage du carbone dans les forêts de l'Ontario, 2000 2100

Cette étude présente des projections décennales en matière d'accumulation de stocks de carbone (C) dans les forêts aménagées et les produits ligneux de l'Ontario, entre 2000 et 2100. Ces projections ont été réalisées grâce à un modèle de comptabilisation du carbone forestier, FORCARB ON, lequel est inspiré du modèle américain, FORCARB2, mais modifié de façon à représenter les conditions qui existent dans les forêts ontariennes. Les résultats sont présentés séparément, selon le type d'activités d'aménagement forestier en cours : les terres de la Couronne aménagées, les terres privées, les parcs et la zone de gestion des feux mesurée. Nous évaluons également le carbone stocké dans les produits du bois provenant des récoltes effectuées entre 1951 et 2000, ainsi que dans les produits qui seront récoltés après 2000. Nous avons établi que, entre 2000 et 2100, 433 millions de tonnes de carbone seront emprisonnées dans les forêts ontariennes. Ce volume correspond à un taux annuel de séquestration du carbone de 4,3 millions de tonnes entre 2000 et 2100, soit l'équivalent de 15,9 millions de tonnes de CO_2. Le plus gros puits de carbone forestier se trouve dans les produits du bois, lesquels fourniront quelque 364 millions de tonnes de stockage de carbone au cours du siècle. Nos résultats démontrent l'importance d'évaluer les tendances en matière de stocks de carbone forestier sur de longues périodes afin d'éviter les effets à court terme des changements dans la structure des forêts. Cette étude nous permet également de conclure que l'exploitation durable et planifiée des forêts ontariennes contribue à augmenter le carbone forestier à long terme.

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